Available online at www.sciencedirect.com

SciVerse ScienceDirect

Physics Procedia 37 (2012) 2072 – 2079

Physics Procedia

TIPP 2011 – Technology and Instrumentation for Particle Physics 2011

Multi-OTR System for ATF2

A. Faus-Golfe[a*], J. Alabau Gonzalvo[a], C. Blanch Gutierrez[a], D. McCormick[b], J. Cruz[b], M. Woodley[b], G. White[b]

[a]*Instituto de Fisica Corpuscular (CSIC-UV), Spain*[c]
[b]*Stanford Linear Accelerator, USA*[c]

Abstract

In this paper we describe the first measurements performed during fall of 2010 and the beginning of 2011. We discuss software development, realistic simulations and new hardware improvements of a Multi-Optical Transition Radiation System installed in the beam diagnostics section of the Extraction (EXT) line of ATF2, close to the Multi Wire Scanner System. 2D emittance measurements have been successfully demonstrated and the system is being routinely used for coupling correction. Realistic beam simulations have been made and compared with measurements. A 4D emittance procedure is being prepared and some preliminary measurements have been performed. An improved optical system including a demagnifier lens to improve the beam finding procedure is being designed and will be installed during the autumn 2011 operations period.
A systematic measurement campaign will take place after recovery of ATF operations (post the 2011 Tohoku Earthquake), then a comparison with wire scanners can be done. This will be a definitive test of the OTR as a beam emittance diagnostic device, which will provide fast beam emittance measurements with high statistics, giving a low error and a good understanding of emittance jitter and sources.

Keywords: Optical Transition Radiation; Beam Size Measurement; Emittance Measurement.

*Corresponding author: Angeles.Faus-Golfe@uv.es.
[c] Work supported by Department of Energy Contract DE-AC02-76SF0051 and FPA2010-21456-C02-01

 doi:10.1016/j.phpro.2012.02.525

1. Introduction

The determination and monitoring of the transverse phase space at ATF2 is crucial in order to meet their performances specifications. Since the beam sizes at the Interaction Point (IP) depend strongly on the aberrations in the Final Focus System (FFS), accurate measurement upstream of the FFS is required to tune the beam sizes at the IP. The beam sizes are measured in several locations in the beam diagnostic section of the Extraction Line (EXT line) of ATF2 to generate an emittance measurement. The vertical beam sizes in the diagnostic section are of the order of 10 μm. This means that the devices have to image spot sizes as small as 5 μm, with better than 10% accuracy. The ATF2 EXT line is a beam line with low power and low repetition rate that make usable devices using solid targets.

In contrast to a ring machine, where an individual bunch can be measured many times as it passes around the ring, the beam size and the emittance measurement in the Linear Colliders (LC) or in the beam lines have to be performed in a single pass. This requires that the wire scan device types (laser or solid) sample across successive bunches within a train, often with an over-estimation of the beam size due to beam position and intensity jitter, and can take up to half a minute to complete the measurement. Although some of these effects could be corrected, as the jitter effect could be subtracted by using the nearby BPMs signals, this can be avoided by using Optical Transition Radiation (OTR) Monitors. These monitors are based on the transition radiation effect, a light cone emitted when the charged particle crosses a metallic interface. This light is emitted in a specular fashion so it can be focused on to a CCD and produces an image of the beam [2]. OTRs are able to take many fast measurements and therefore to measure the emittance with high statistics, giving a low error and a good understanding of the emittance jitter.

2. The beam diagnostic section of the ATF2 Extraction Line: Optics Studies and Beam Spot Size Simulations

The transport beam line from the Damping Ring (DR) to the FFS of ATF2 is called the EXT line [1]. The ATF2 EXT line is divided in three regions as shown in Figure 1: the first section or extraction part shared with the DR, the matching section and the diagnostic section. Instrumentation equipment such as: Button Beam Position Monitors (BPM), Strip-line BPMs, Beam Current Monitors (BCM) and filament Wire Scanners (WS) from ATF are re-used in the new ATF2 EXT line. Furthermore four OTRs (labelled as OTR0, OTR1, OTR2 and OTR3) have been installed close to the five WSs (labelled as MW0X, MW1X, MW2X, MW3X and MW4X) [4]. These four OTRs are known as the multi-OTR system.

The measurement of beam sizes and emittances of the extracted beam from the DR is made by means of the WSs and the multi-OTR system. Moreover, the proximity to the WS will be a definitive test of the OTR as a beam diagnostic device.

Optics studies and tracking simulations with MAD8 program [5] have been made. The beam spots calculated from the optics are big enough not to damage the target and they are comparable to these on the WS. Comparison with the WS beam spot sizes are found in table 1. The input beam for the MAD8 simulations was 50000 particles with Gaussian distribution in x, y and energy, and with energy spread of 8.00×10^{-4}.

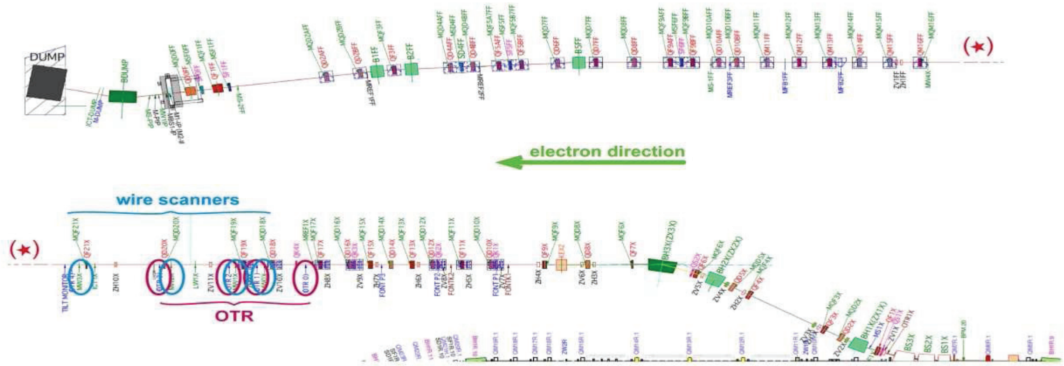

Fig. 1. Layout of ATF2 EXT line.

Label	*Units*	*OTR*		*WS*	
		σ_x	σ_y	σ_x	σ_y
0	um	118	9	82	11
1	um	148	8	157	7
2	um	92	12	88	13
3	um	144	7	151	6

Table 1. Simulated Beam size comparison in OTR and WS locations.

Furthermore tracking simulations have been made comparing the sizes in the OTR locations obtained with the codes MAD8 and LUCRETIA [6] and the simulation of the CCD image obtained using LUCRETIA obtaining in all the cases similar results.

3. Technical Description of the Multi-OTR system: Optical and Mechanical Design

This OTR system design was an evolution of a previous system placed in the EXT line [3] of the previous configuration of ATF prior to 2008. It includes some new modifications related to the optical system, the target actuator, the target material itself, the OTR main body and the total footprint, as shown in Figure 3 [8]. Four of these OTRs were installed in the present EXT during the first half of 2010, one of them is shown in Figure 4 (b). The commissioning and successful testing of the complete system was completed in the autumn of 2010. Also during 2010 some other improvements have been incorporated into the installed OTR system.

A wire card with a set of 10 µm tungsten wires is mounted below the target. The beam size can now also be measured using the OTR mover system by moving the wires across the beam while detecting the Compton scattered photons in the background detector of the IP beam size monitor. This allows the optical OTR measurements to be compared with a wire measurement made in the same location. The targets with the wire system are shown in Figure 4 (a). The calibration system now includes a small lamp that can be inserted into the beam pipe to illuminate the target when there is no beam. This provides enough light on the target to perform a more accurate calibration of the optical system.

Current operational experience with the OTRs has identified a needed optical change that is in the process of being implemented. With the current magnification, using a 10X lens, the field of view is only about 250um square. Small beam orbit shifts can mean that when the target is inserted there is no beam spot to be seen. This often requires a lengthy search, using the OTR movers to re-establish the beam image in the field of view. The 10X magnification is ideal for measuring the Y spot size but the X spot doesn't fit in completely in the image. To deal with both these issues a zoom system is to be installed before the start of the fall 2011 running. This will reduce the magnification a factor of 2 ensuring the entire X spot is in the image and reducing the need for time consuming image hunts after shifts in the beam orbits.

Two target materials are now in use. Aluminized kapton 2 μm thick is used for OTR 2 and 3, and 1 μm thick aluminum foils are used for OTRs 0 and 1. Presently both materials have withstood beam intensities of 1e10 electrons per pulse and spot sizes of about 200 μm in X and 60 μm in Y.

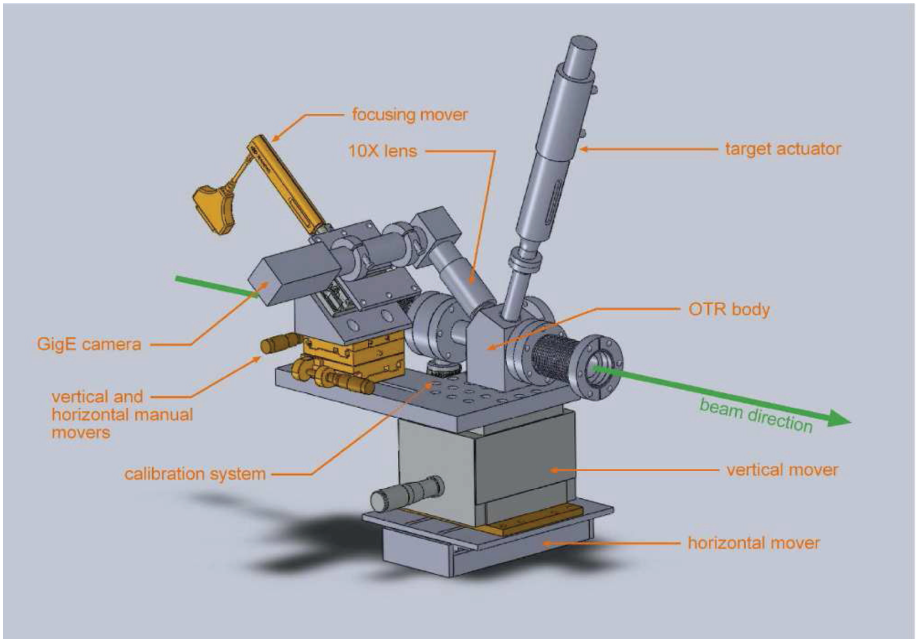

Figure 3: OTR Design

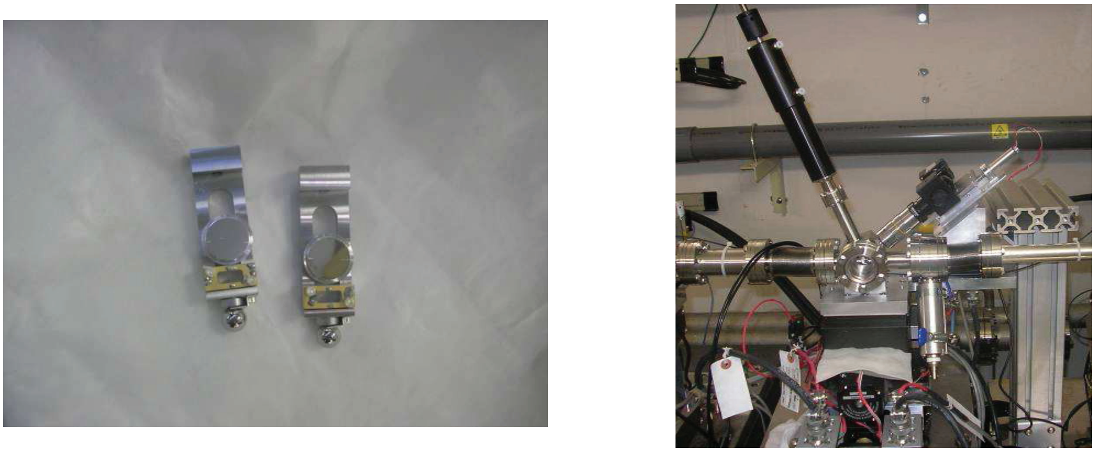

Figure 4 (a) Target holders and wire cards with the targets; (b) OTR with the calibration system installed at ATF2.

4. Software Development and Integration

The user interface is programmed in Matlab and includes basic control functions, such as OTR horizontal and vertical motion, target insertion and removal, focus control, machine protection alarms, and single-OTR data analysis functions for beam size measurement. The control software uses simultaneous information given by the four OTRs and the Flight Simulator (software running the online model for ATF2) (FS) [7] to calculate the emittance and perform other analyses.

The emittance reconstruction algorithm is based on the one used for the WS [9]. Occasionally, this algorithm has been observed to have an issue regarding the generation of imaginary emittance results when measurement errors are of a too high level [10-12]. This is not a big problem here since the mOTR takes less than a minute to perform the emittance measurement and the size is not over-estimated due to the jitter. A simulation-based analysis was performed to understand the limitations of this algorithm as it pertains to this OTR system, which is presented below. A 4D algorithm that will take into account the additional information given by the direct imaging of the beam ellipse (the tilt of the beam ellipse at the OTR locations) is under study. This will allow determination of the coupling terms and give us the possibility of correcting these with a single set of measurements rather than scanning the emittance with different skew-quadrupole settings as is currently required.

Other functions to be implemented include automatic beam finding using information from the surrounding beam position monitor systems, automatic coupling correction, and an auto-focus mechanism.

5. Calibration and First Measurements

A calibration of the positioning system for all OTR devices was made in December 2010.To calibrate the scale, an OTR is moved in one direction and the centroid position versus the mover position curve is fitted. To determine the roll alignment of the system, the beam is steered in one direction using an upstream corrector magnet whilst recording the centroid position in the other axis. This aligns the OTR system in the same co-ordinate frame as that of the corrector magnets. Other accelerator components are so-aligned, leading to a common co-ordinate frame. The system gives a single bunch size for each OTR and, after the targets are correctly aligned, provides an emittance measurement along with a statistical error in less than a minute. The measured beam sizes were crosschecked with the wires installed in the target holder and the WS system. Emittances around the nominal ones were obtained in the tests with about 10% measurement-measurement fluctuation (Figure 5). From autumn 2010 until March 2011, the OTRs were used during ATF2 beam operations for emittance measurement and coupling correction. Figure 6 shows the mOTR system being used for coupling correction by changing the strength in four upstream skew-quadrupole magnets and looking for the setting in each one that minimises the measured emittance.

Realistic beam simulations were made and compared with the measurements. Table 2 shows the results of the comparison between realistic beam simulations and measurements as in Dec. 17th 2010 while Figure 7 shows a set of horizontal beam size measurements as function of time performed on March 6th 2011 as an example.

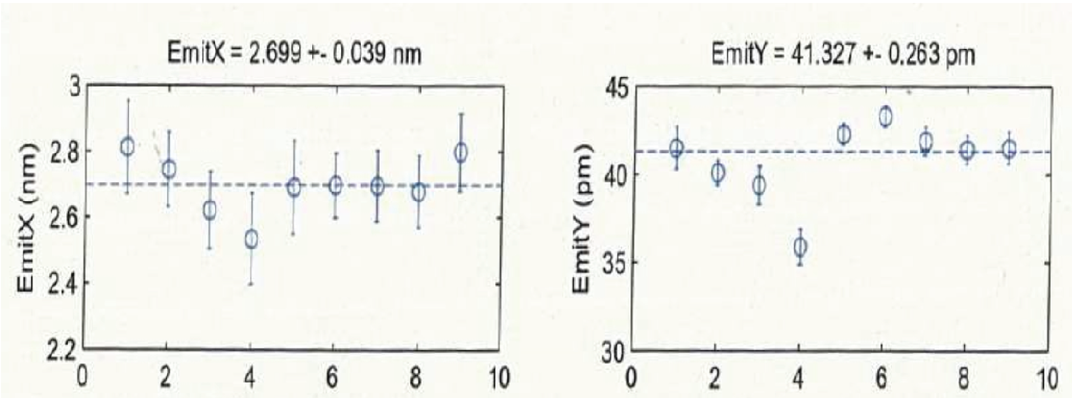

Figure 5: A set of systematic measurements (Dec 2010).

Label	*Units*	S_x		S_y	
		Nominal	*Measured*	*Nominal*	*Measured*
OTR0	um	113	105.9 +-0.8	8	16.6 +- 0.2
OTR1	um	147	126.4 +- 0.6	7	13.85 +- 0.14
OTR2	um	90	77.1 +- 0.6	11	19.0 +- 0.3
OTR3	um	138	182.9 +- 0.7	8	16.9 +- 0.3

Table 2: Comparison between beam simulations and real measurements with statistical error (Nov. 12th 2011).

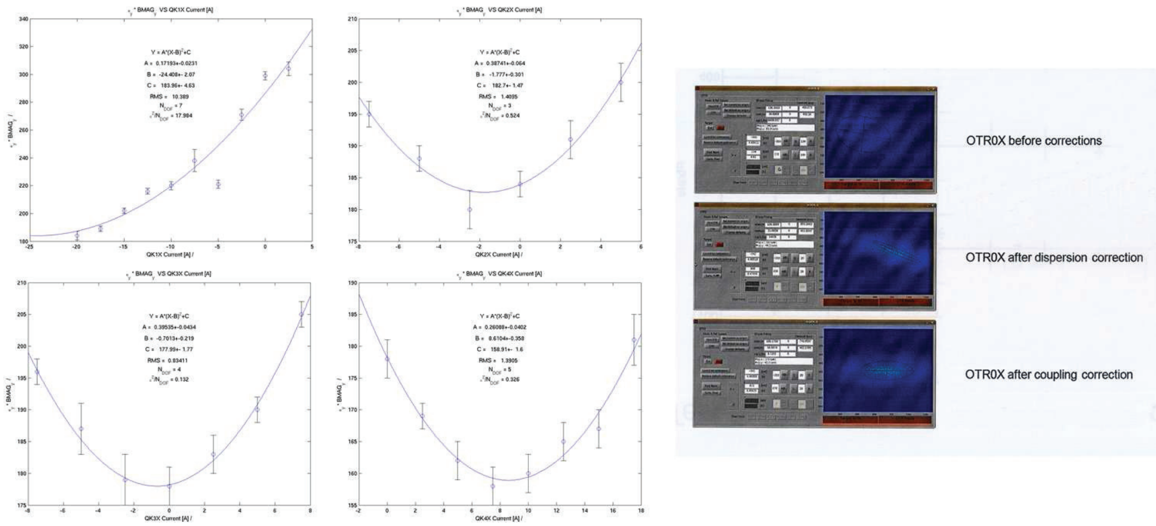

Figure 6: Coupling correction of the ATF2 EXT line by using the OTR (Nov. 11th 2011). The four-fitted parabola corresponds to the minimisation of the vertical emittance against the skew quadrupole intensity for each of them.

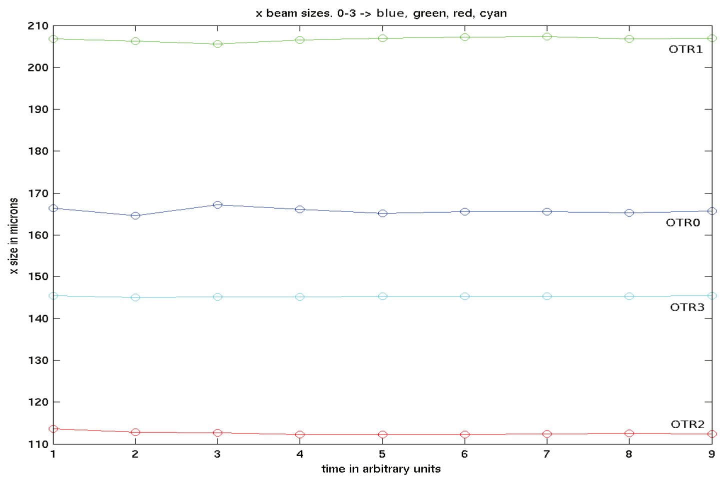

Figure 7: Set of σ_x measurements in function of time taken on March 2011.

6. Emittance Algorithm Studies

Simulation studies were performed to understand the limitations of the emittance reconstruction algorithm that is sometimes observed to give imaginary values for the calculated emittance. The fraction of non-real emittance values was calculated as a function of input accuracy of the beam size measurements at the OTR locations and the degree of coupling put into the simulated beam.

Figure 8 (a) shows a comparison between the calculated emittance value and the input emittance. The blue solid line shows the mean value of 10000 emittance calculations, the dashed lines show the +/- one-sigma values. The green line shows the input beam emittance. With a relative beam size measurement error below 10% there is a systematic over-estimation of the emittance at the level of about 4%. Taking as an example a 5% error in the beam size measurement, Figure 8 (b) shows a histogram displaying the simulated reconstructed values. The blue line is the mean measured emittance and the green one is the input. The systematic relative error on the emittance reconstruction in this case is 1.9%. For the 5% measurement error the emittance statistical jitter is around 10%, which is in agreement with the 10% measurement-measurement fluctuation given above.

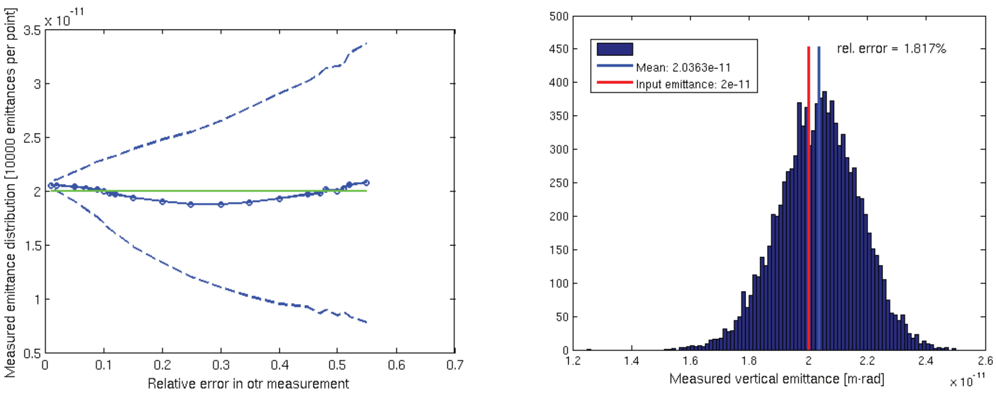

Figure 8 (a) Comparison between input and mean of calculated emittances; (b) Calculated emittance distribution for a 5% size measurement error. 50k emittance calculations

Acknowledgements

We would like to thank the ATF group at KEK for all the support, especially N. Terunuma for his continuous help on the installation

References

[1] ATF2 Group, "ATF2 Proposal Vol.1, CERN-AB-2005-035", (August 11, 2005).
[2] J. Bosser et al, "Optical transition radiation proton beam profile monitor", Nuclear Instruments and Methods in Physics Research A238, (1985), 45-52.
[3] M. Ross et al, "A very high resolution optical transition radiation beam profile monitor", SLAC-PUB-9280, (2002).
[4] H. Hayano, "Wire Scanners for Small Emittance Beam Measuremet in ATF", XX International Linac Conference (2000).
[5] H. Grote and C. Iselin, "The MAD Program (Methodical Accelerator Design)", CERN SL 90-13 (AP)
[6] The LUCRETIA Project, http://www.slac.stanford.edu/accel/ilc/codes/Lucretia/
[7] G. White et al, "A flight simulator for ATF2: A mechanism for international collaboration in the writing and deployment of online beam dynamics algorithms", EPAC08, Genoa, TUPP016, (2002).
[8] J. Alabau, et al, "Multi optical transition radiation system for ATF2", IPAC10, Kyoto, 2010
[9] M. Minty and F. Zimmermann, "Measurement and Control of Charged particle Beams", Springer, Berlin 2003.
[10] M. Woodley, "Simulations of intrinsic emittance measurements in an ideal 4D diagnostic section: coupled input beam", ATF 99-07.
[11] M. Woodley, "Simulations of intrinsic emittance measurements in ATF EXT line", ATF 99-08.
[12] I. Agapov et al, "Beam emittance measurements with laser wire scanners in the International Linear Collider" Physical Review Special Topics – Accelerators and Beams 10, 112801 (2007).